

Resilience of People Movement During Natural Disasters

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Abstract

Natural disaster causes a serious threat to large urban areas. It is important to comprehend and predict the mobility of humans to evaluate occupant's liability, resilience, and developing strategies for disaster evacuation, quick response, and aid. But a limited investigation has been done on the consequences of natural tragedies on the movement of humans. In this article, we have demonstrated how a single disaster affects patterns of human movement in town areas with the help of twitter data for individuals' movements. In current studies 15 damaging cases across five sorts of a catastrophic event and dissected the human movement information previously, during, and after every occasion, looking at the perturbed and consistent state movement information. The outcomes propose that the force law can portray human portability in most cases and that human versatility designs saw inconsistent states are regularly corresponded with those in perturbed states, featuring their innate resilience. Notwithstanding, the quantitative investigation tells us that this resilience has its cutoff points also it can come up short in increasingly amazing cataclysmic events. The outcomes of this study will elaborate our comprehension of the cooperation between town tenants and common foundation, improve our capacity to anticipate human movement designs during catastrophic events, and encourage possibility arranging by policymakers.

Introduction

Natural disasters impose a severe risk to inhabitants of urban areas. Different surveys are conducted to evaluate the number of people affected by natural disasters [1]. This situation will never get improved unless the change in climate could be predicted by the help of previous records. Governments and metropolitans have developed many procedures to overcome problems caused by unusual destructions, among which evacuation and reactive strategies are the most vital constituent [2]. These strategies gauge the potential dangers presented by various sorts of disasters and endeavor to govern and limit the consequences. In any case, the effectiveness of these top-down plans is regularly addressed, since they may need adequate comprehension and don't consider real-world human practices. Study shows that most people neglect the compulsory order to travel inland, about 50% failed to do so. Lamentably, a large portion of the fatalities happened in these clearing regions. A comparable circumstance happened in the Philippines after one year when Typhoon Haiyan hit the Tacloban city [3]. Though the authorities requested city occupants to empty and look for cover before the tropical storm's appearance, rather than moving to higher ground, many took shelter in concrete buildings that couldn't withstand the quality of the breeze and the going with flood water and numerous lives were lost when the buildings collapsed [4]. A previous study shows that people who evacuated were not safe, according to the U.S. Federal Emergency Management Agency (FEMA) revealed statistics that flood effect is much larger than estimated selected regions. Many people who migrated to expected harmless regions also vanished their breaths. After this, defined safe zones are updated on the base of this experience. These situations allow us

to understand people's reactions when a certain type of disaster meets an area[5]. It also highlights the necessity of understanding how people counter, in the scenario of the evacuation of the habits and patterns of movement, in severe events[6].

Human gets displaced in the response of natural disaster. Most importantly, human migration tells us about the readiness of evacuation. There will be a loss of lives if there is overcrowding and crushing during emergencies. Moreover, they also cause severe injuries[7]. It has been observed, intimation before the occurrence of disaster may lead to traffic jams on the roads. There was an unfortunate city-wide traffic jam when all people crammed onto the road after snowstorm warning in the U.S. city of Atlanta, Georgia. Consequently, several of them get stuck when storm meets the area, hence they had no option to left their vehicles on roads and seek shelter. If there is no deeper understanding of the same situations may occur again[8]. So, it is crucial to understand human movements during emergencies. Human mobility effects information, communication infrastructure during an emergency[9]. Once IT infrastructure gets affected by a disaster, mobility of the human accurately evaluates bandwidth of emergency Information technology network. It causes diffusion of speed and width of information. Peer-to-peer connections able to create pocket switched networks using different types of mobile cell phones. These networks are very useful for communication between peoples and helping hands. Furthermore, a temporary network can provide disaster specific information about severe danger and evacuation routes. It reduces injuries ratios, hazardous collateral damage, and infrastructure loss[10]. Moreover, perfect human mobility prediction can save lives. If it had been easy to realize affected individuals inside the area of emergency, some people might have been spared. Above elaboration allow us to build our understanding about real-world behavior of human during natural disasters. It allows us to conduct depth investigation of human mobility[11].

Despite its significance, a little investigation into human portability has been accounted for identification with portability affected by natural disasters, for example in perturbed states. Generic characteristics have been discovered from which specific patterns could easily determine[12]. Fragmented human mobility generally depends on perturbed movement concerning the severity of the condition. Almost, this type of investigation involves one case or the same type of natural disaster[13]. Moreover, with these studies, we are unable to relate it to any other event. To address this state of the problem, the given research article initiates a step towards the enrichment of patterns in perturbed human mobility by analyzing human movement during different types of natural disasters[14]. This investigation depends on an enormous amount of human development information gathered from Twitter. This information assortment exertion has taken very nearly two years, furnishing us with human portability information for various distinctive natural destructions around the globe, which includes the tropical cyclones, dense rainstorms, winter storms, wildfires, and earthquakes. By examining the information from these disasters, we endeavored to reveal general patterns in the developments of a perturbed urban population[15].

This article structured as follows. After scrutiny of literary work about human mobility and how it could be affected by the potential natural disaster, we have proposed six assumptions. Then in the next sections, data collection and methodology are elaborated. Proceedings section are results, revealed findings, and hearings. Finally, it is evaluated by addressing the limitations of this study and is followed by conclusions.

Literature Review

There has been a lot of investigation into general human movement patterns. By using current data and mobile data, investigations show that human mobility follows a power-law distribution. Levy flight model found in animal movement patterns and it also adopts by a human[16]. It is concluded that the singular

movement trajectories revealed the same shapes after scaled by the radius of gyration. Three unique characteristics have been observed using the data which was collected by 1 million mobile phone users[17]. Even, it was impossible to evaluate these properties by the help of Levy flight model and generous continuous-time random-walk model. Characteristics were: (1) a diminishing propensity for an individual to visit new areas; (2) frequency to visit different locations are uneven; and (3) an ultraslow diffusion, return to the previous location. Based on these outcomes a new model has been developed named individual mobility. This model demonstrates preferential return and exploration. Furthermore, it is more presentable than other models and it is more accurate in the case where there are long flights. It accumulates long-term spatial and temporal scaling patterns[18].

Human movement at the city scale has likewise been explored. At this level, occasional regulations describe human movement. In an investigation, researchers found human movements in 31 large cities adopted power-law distribution[19]. Mostly, all revealed patterns of human mobility are similar. Moreover, in several cases, there are periodic patterns based on 7 days or 24 hours. Human movements have likewise been appeared to follow profoundly proficient direction setups during their day by day movements. People are proficient when engaging in their routine trips, they tend to use 17 trajectories from million available trajectories[20]. Patterns that have been observed in urban areas allow prediction and simulation of movements in urban territory. Furthermore, this type of research enables us to understand the future effect on transportation blueprint and urban spatiotemporal interaction[21]. Coupling marvels between human movement and social ties and exhibited that a person's informal community has corresponded with versatility conduct. Such a finding isn't in particular critical to comprehend human portability inconsistent states, yet additionally can assume a key job in anticipating human portability in catastrophes and crises. Literature states, the social framework is a major building block to minimize collateral damage and hoard lives during emergencies[22].

In emergencies, information tends to diffuse globally however in non-emergency situation data is locally constrained. In normal routine there are no globally adopted patterns, it is based on the local community. This investigation is revealed from the mobile phone billing data during the emergency and non-emergency events[23]. The effect of weather has been also discussed in the past to demonstrate the significance of human mobility. Furthermore, the weather also plays an important role in the daily activities of a specific urban area. From this, we come to know that uneven event affects people activities badly. Emergencies cause people to migrate from the mean position[24]. A researcher investigates people move involuntarily in case of natural disaster from the data which was collected in 8 years for the sake of research. In another research, a researcher found 20 percent of the population migrate in earthquake and disease infection with the help of cell phone data[25]. A few cases are observers to an immediate connection between human relocation and pandemics/plagues. While these examinations show that human advancement directions during catastrophes do veer off from their run of the mill predictable states, research around there is isolated and deficient effort has been committed to discovering key models in human versatility under the effects of cataclysmic events[26]. Various factors have obliged progressively wide and all-around research, notwithstanding, a key issue is the inborn erraticism of cataclysmic events. Current advancement is up 'til now inadequate in envisioning the occasion of cataclysmic events, for instance, seismic tremors and typhoons, and even though we by and by having some preemptive direction of specific sorts of catastrophic events, particularly tropical twisters, winter storms, and rainstorms, researchers and specialists are so far ill-suited to accurately check their definite ways, quality, and effect [27].

The disappointment of one of the world's most evolved nations to limit the harm from a noteworthy approaching natural disaster when the destruction it had unleashed in two different nations

had been including on the nightly news for quite a long time features the difficulties associated with shielding urban inhabitants from natural disasters[28]. This capriciousness additionally makes it hard to gather experimental human development information from numerous kinds of natural disasters, what's more, in this manner specialists have restricted information available to them when trying to inspect the principal qualities of annoying human mobility[29]. Resilience is an indicative parameter for measuring the vulnerability of human mobility when meets natural emergencies. Moreover, it is one of the foundation attributes[30]. It could help anticipate human movements in urban zones and shed new light on the interdependence between human migration and other substructure, giving priceless information that will help characterize the state of the dynamic landscape for socio-ecological frameworks. Limited research has been carried out to understand and quantify the reliance on migration from one to another place. A study elaborates human mobility possesses inherent resilience[31].

Power law holds tightly in most of the natural disaster cases such that values for the center of movement and radius of gyration are correlated with their values whereas the state would be steady. This relation demonstrates the probability of perturbed mobility patterns. Instead of all disaster practitioners only discuss a single disaster. So, they were unable to relate this with any other natural disaster. There is a basic drawback in research on human mobility irritation and versatility affected by various kinds of natural disasters. Such examination is basic for foreseeing human movements during natural disasters and investigating the interdependence between human versatility and common foundation. At last, a superior comprehension of human versatility in exceptionally unpleasant disaster circumstances will advance open security by distinguishing the best approaches to anticipate human areas and travel designs, in this manner encouraging the assurance of defenseless people from likely damage and injury[32].

Hypothesis Development

Because of the outcomes from past investigations, we set a few assumptions to inspect the mobility of human's strength. Versatility among people portability alludes toward the capacity of human development to retain stuns, keep up its central properties, and come back to its consistent state harmony in reaction to unusual ruins. These speculations at that time tried for every natural destruction. As referenced before, human portability can be portrayed with the help of power-law, also albeit extraordinary climate can fundamentally impact human movements this power-law holds in any event in solid disaster. Hence we propose the following hypothesis:

Hypothesis 1: All the disasters hold power-law.

The power-law is a functional relationship between two standing quantities. In which the proportional change would because of changes in others. There may be a direct relation or inverse relation between them. The movement of the inhabitants depends on the severity of a disaster. Power-law holds in most of the cases and also used in literature by many researchers. We are going to discuss the severity of the natural disaster concerning their type, time, and places of occurrence. It is a very useful feature to illustrate the whole picture of disasters[1],[33].

Hypothesis 2: Do all evaluated distances give perfect results for all types of disasters.

We are going to evaluate different distances such as Mahalanobis, Euclidean, and Manhattan distance using the coordinates of tweets. From all of them, we conclude the most suitable distance for such cases where the coordinates of the earth are given[34]. Empirical work was done using Euclidean distance. This is our main feature of quantitative work. We apply three distances from which we found Manhattan as the most prestigious.

Hypothesis 3: Do general trends in a similar type of disasters remains the same.

There are mainly five types of disasters that we are going to explore. We will check the trends in the same type of disasters remain the same. Either people move before and after the occurrence of the disasters are the same[35]. If they are different in the same type of disasters how much different they are. In literature, it was observed that mostly all disasters tightly hold power-law and same properties.

Hypothesis 4: Does affected people positively correlated to movement before the disaster.

Once the warning was given for a specific disaster. Many people take precautionary measures what would be Impact of movement on the collateral damage after taking precautionary measures. Movement patterns are briefly discussed in this article[36]. The results of their evaluation give us a direction to propose a hypothetical statement.

Hypothesis 5: Does damage is directly proportional to thenumber of people who ignored the prior instructions that were given to them before the disasters.

In this part, we will discuss the role of the people who do not take precautionary measures before the disaster. Their behavior or movement they tend to use just after the occurrence of the natural disaster. This assumption made on the base of the power-law distribution mentioned in many articles cited in our article[37].

Hypothesis 6: Do all the disasters of the same type have the same impact.

We will be going to explore the after-effects of a disaster. Moreover, their effects in a certain area. Several effects were discussed in this article. Contrary to this, many other post-effects are also discussed in this[38].

Data Description

Mostly, mobile data was used to conduct this type of research. The information accuracy of these examinations is restricted to the inclusion zone of every mobile phone tower, which is regularly around 3-4km. Whereas such preciseness has been instrumental in building up a comprehension of universal examples of human versatility over larger scale such as a nation-state or astate, it might come up short on the important preciseness to catch versatility changes brought about by disasters and other outrageous situations that develop at littler scopes (a city)[39].

Twitter was utilized to gather high-goals human portability information in the investigation. It is an online social interaction site that permits individuals to post statuses that are constrained to 140 characters, termed as tweets. It devours more than 645 million nimble users. Furthermore, these users post around 500 million tweets each day. Clients can empower a capacity which naturally consists of area data, called a geotag, to every tweet they post. Each geotag contains the topographical organize at which the tweet was posted[1]. Various examinations have used the stage to consider correspondence and geo-person to person communication. Utilizing the Twitter open API, we built up a strategy to gather geotagged tweets the world over. Human portability information previously, during, and after fifteen natural disaster occasions from five kinds of natural disasters were gathered to lead this investigation. At that point, we checked on natural disasters that happened during the period and recovered human versatility information from the influenced urban zones. We recognized fifteen disasters that gave adequate information for the investigation[40]. These disasters partition into the accompanying gatherings: 4 tropical storms, 3 extreme

winter storms, 3 quakes, 2 rapidly spreading fires, and 3 severe rainstorms. An outline of these occasions and information can be found in Table 1.

Table 1. Disaster Details

Disaster Details			
Disaster Type	Disaster Name	Location	People Move
Typhoon	Wipha	Tokyo, Japan	708453
Typhoon	Halong	Okinawa, Japan	85779
Typhoon	Kalmaegi	Calasiao, Phillipines	21698
Typhoon	Rammasun_Manila	Manila, Phillipines	408758
Earthquake	Bohol	Bohol, Phillipines	57303
Earthquake	Iquique	Iquique, Chile	7648
Earthquake	Napa	Napa, USA	19009
Winter Storm	Norfolk	Norfolk, Britian	57508
Winter Storm	Hamburg	Hamburg, Germany	7526
Winter Storm	Atlanta	Atlanta, USA	78589
Thunder Strom	Phoenix	Phoenix, USA	289866
Thunder Strom	Detroit	Detroit, USA	382674
Thunder Strom	Baltimore	Baltimore, USA	164440
Wild Fire	AuFire-a	New South wales(AUS)	21637
Wild Fire	AuFire-b	New South wales(AUS)	32185

Data Analysis and Results

To investigate the significance of the suggested hypothesis. We directed different examinations on human mobility on available data. To verify the first hypothesis and evaluate whether power-law hold in all types of natural disasters or not[41]. We calculate the fundamental displacement for its verification. We apply three formulae to justify our first hypothesis. First, we evaluate Euclidean distance by giving the longitude and latitude. The following formula is used to evaluate distances.

$$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Where the x_2 and y_2 are the final positions which were adopted by the people whereas x_1 and y_1 are their initial position. In our case, the value of x represents latitude and y represents longitude concerning their every user. As we know the Euclidean distance is the straight distance between two points known as displacement so it does not look too suitable in our case. Moreover, due to this feature, some of the distances become zero due to the inputted coordinates (Longitude and latitude). In the real world, there is non-uniformity which doesn't allow us to solve this particular problem. So while keeping this in mind we have applied Mahalanobis distance to evaluate the distance column for each of the tuple of an individual. Finally, we come up with the Manhattan (City Block) distance which is the most prominent distance factor to calculate the proximity. For that, we use this formula.

$$|x_2 - x_1| + |y_2 - y_1|$$

Where the x_2 and y_2 are the final positions which have been adopted by the people whereas x_1 and y_1 are their initial position. In our case, the value of x represents latitude while y represents longitude concerning their every user. This is a suitable distance for our research work because it is to believe that the distance is the city block and not the straight line. To justify the significance of our work. We determine the number of people move during natural disasters.



Figure 1. Number of People Move During Disasters

In current research work, there was a total of five types of disasters named typhoons, earthquakes, winter storms, thunderstorms, and wildfire[1]. All types of disasters possess certain similar properties which tell us what type of precautionary measures are essential in what type of disaster. The number of people who

moved to a certain type of disaster is similar. It tells us the consequences of a specific disaster[2]. Table 2. elaborate on the number of people who migrated or moved before, during, and after the disaster.

Table 2. Number of People Move

Number of People Move				
Disaster Type	Before Disaster	During Disaste	After Disaster	Total
Typhoon	332706	472122	417860	1222688
Earthquake	41784	4533	37643	83960
Winter Storm	55272	29159	59192	143623
Thunder Strom	661735	19373	155872	836980
Wild Fire	15151	21613	17058	53822
Total	1106648	546800	687625	

In typhoon total number of people moved is 12, 22, 688 which is the largest number of all the disasters. This annotates typhoons are most dangerous among all-natural disasters. The number of people moved after the occurrence of the disaster is greater than the movement before the occurrence. It is compulsory to impose on people to move from the places where typhoons are expected. So caution should be taken in specific areas before the disaster. If we can manage the mobility before the occurrence of the disaster we can minimize the collateral damage. In an earthquake, there was a total of 83, 960 people. Moreover, the number of people moved before and after the occurrence of the disaster are the same. These graphs tell us the rapid increase in the number of people once the earthquake occurred. So estimation could be escalated as no one can predict the assurance of the occurrence. But if there is a chance of an earthquake in certain area precautionary measures should be taken earlier. With the help of these measures, collateral damages could be lessor. In the next section, we described the areas where the operation could escalate first.

In winter storms the total number of people who moved out of their mean position is approximately 1,43,623. From these numbers, about 41% moved after the disasters. So we conclude several people didn't move before the occurrence which caused sudden movement after the occurrence. The number of people was increased after the disaster. It is recommended that there should be evacuation plans once there is the forecasting of such disaster in a certain area. The movement of people should retain even after the average of 16 days after the occurrence. In thunderstorm 8,36,980 were marked themselves as moved people. Their coordinates were changed concerning their time they were tweeted. In this disaster, the most prominent factor is people took it seriously and have moved even before the occurrence of disasters. 79% of the people were there before the area meet the disaster. In wildfire total, 53,822 people moved out from their mean or parent position[42]. The movement in such types of disasters is relatively high during the occurrence while the movement before and after remains the same.

Discussion

Outcomes of this study indicate that catastrophic events influence human developments in suburban territories, even though the effect can shift as far as seriousness and length[43]. In this area, we demonstrate the consequences of every one of our theories according to past exploration and its suggestions for succeeding examination and execution. These discoveries add to our comprehension of the annoyance and flexibility of movement during cataclysmic events[44],[45]. Power-law does not hold tightly in most cases of disasters. Mostly, the same type of disaster follows the same trends or patterns such as the movement of people before, during, and after remains the same. In winter storm and thunderstorm people follow the instructions and they move before the area meets the disasters. People

choose to move according to their need that's why mostly they move after the occurrence. Mostly, the same type of disaster has the same type of impact on society[46].

In the first hypothesis, we suppose human disasters hold power-law in case of all-natural disasters and the power-law is firmly responsible for human mobility. Results show that perturbed movements are purely governed by power-law however in some cases it's not[30],[47][57]. These findings align with prior research that shows human mobility follows power-law but not in the case of thunderstorms. The major difference between the revealed patterns is due to the fact datasets are different in different research[48]. Moreover, the precision of data also matters in the case where we obtain the number of people move during emergencies. Our data consist of compact location attributes (Longitude and Latitude) which arise the contradiction regarding the adaptability of power-law in all type of natural disasters[49]. While past exploration has shown that human mobility follows comparable circulation in huge populace communities, the outcome reveals that human mobility is progressively an all-inclusive pattern. We concealed collateral damage reduces if people move on the warning before the disaster occurred. But in earthquake people tends to move after the occurrence of disasters[50].

A practitioner uses the Harversian formula for investigation however we use Manhattan, Euclidean, and Mahalanobis for the determination of displacement metrics[51]. We found Manhattan as the most prestigious distance where the coordinates are given. So, for such types of investigations where earth coordinates are involved, we can use Harversian and Manhattan distance formula. Moreover, Euclidean and Mahalanobis are good options[44]. With the given data we conclude the similar type of disasters impose a similar impact on human mobility and this is supported by the statement power-law hold in perturbed and steady-state[52]. The number of people affected in a disaster is directly proportional to the severity and the precautionary measures taken. All the hypothesis depends on the acceptance of power-law distribution in human mobility during natural disasters. Hypothesis 5 and Hypothesis 6 are pathetic to understand under the influence of emergencies[53]. A certain number of people may affect power-law badly concerning the severity of natural disasters. For long, we can say that perturb patterns collected during steady-state cannot demonstrate or predict patterns for emergencies[54].

The destruction that occurred naturally has a mind-boggling impact on mobility. If we take the 2014 earthquake of Iquique and the 2013 Earthquake of Bohol as models. They have made territorial human mobility loses resilience and various property losses. The Iquique quake, its greatness of 8.2, was the most grounded seismic tremor that happened in 2014. It affected a city of around 180,000 occupants, what's more, produced 6 setbacks. The 2013 Bohol quake had a size of 7.2. It assaulted Bohol with over 1.2 million tenants and brought about the passings of more than 200 individuals. These multifaceted nature could be seen in the Winterstorm Xaver that affected quite a bit of Europe[1],[2]. While it altogether affected human mobility in Hamburg, Germany, Norfolk, Britain withstood its sway with high resilience. Unraveling the multifaceted nature is past the extent of this examination, yet further examination is expected to assess the different influences and decide the stage after that mobility of human resilience collapses[55].

Limitations

we will incorporate some ideas looking for better data collection methods so that the outcomes will be better. Besides, Harversian distance was used in prior research but we use recommend Manhattan distance as more accurate in the case where respective coordinates are given. We may use this research and previous research to evaluate better comparison results. Furthermore, it is promising research that how to use fewer reference data for evacuation and reactive plans whereas the result is better than as before. All

work carried out is based on a twitter dataset which may not give us a very brief view. However, if we have both data which is collected from twitter and cellular data we would be able to elaborate it more precisely. Besides, the dataset contains information from several regions except for Africa and Asia. So, the results may vary for these regions. Moreover, twitter has certain limitations in some places. In the case of Iquique, the number of records is less than the others so it affects the accuracy of the results.

Conclusions

Human Mobility is directly affected by natural and human-made disasters. Till today, it is revealed that natural disasters are the cause of temporary and permanent migration. Human behavior is impacted by the atmosphere and it would cause migration due to change in their need. This research uses empirical data collected from Twitter to obtain disturbance patterns in human mobility. It has been observed whether the movement patterns before and after the disasters remain the same or not[6]. The whole work analyzed by the number of people move during disasters. Our findings annotate that: (1) Not all the disasters hold power-law such that in case of thunderstorm people deviate from power-law distribution; (2) All the methods for measuring distance are not likely to give perfect results, Manhattan is the best distance measuring parameter for Twitter data; (3) in a gravenatural disaster, the mobility of human becomes more unstable and evaluated correlation might be lost; (4) General trends in same of disaster does not remain same. In a disaster people move just on warning while in the same type of disaster people neglect warning; (5) Collateral damage does not depend on the number of people move before the disaster meet a certain area; (6) Most likely, the same type of disaster impact same results.

The outcomes from the observational information uncovered that the power-law keeps on administering movement of people during a natural disaster instead of some cases. This outcome bolsters the discoveries from a few investigations of universal arrangements of movement of people. In the previous studies, the mobility patterns of people according to the specific type of disaster are not explained, We shed light on the assumptions regarding power-law that are part of the literature but not justified accordingly. It contributes to discovering specific patterns from different types of natural disasters where power-law does not hold firmly. In an earlier study, it has been demonstrated the number of people move during the natural disaster is correlated with steady-state human migration[22],[27].

While this examination gives the first endeavor to look at the movement of human annoyance over a scope of types of natural happenings, the forthcoming examination will be to expand on its discoveries by broadening this way to deal with extra sorts of natural events and joining other powerful factors as autonomous factors that may, or may not, be corresponded with the mobility patterns. Such future exploration will help distinguish the elements that contribute altogether to human mobility bother[43]. It will help in developing strategy producers and professionals to more readily foresee human developments and expand calamity clearing, reaction, and recuperation plans[56].

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